LARP

BNL - FNAL - LBNL - SLAC

# LARP BEAM INSTRUMENTATION

A. Ratti, LBNL

and many others

Fermilab

October 27-28, 2008

# Outline

- Progress update of existing instruments
  - Schottky Monitor (lead by FNAL)
  - Chromaticity Feedback (lead by BNL --> FNAL)
  - Luminosity Monitor (lead by LBNL)
  - AC Dipole (lead by UT --> BNL)
- Most of these transition to Beam Commissioning in FY09
  - Not all lumi monitors are now installed but plan to have all system installed well in advance of 2009 run
- New tasks
  - LHC RF Controls Modeling (lead by SLAC)
- Integration at CERN

# Introduction

First Four instruments are approaching completion at different stages

- Schottky monitors are delivered, installed and bench tested
- Luminosity monitors are in final production
  - - will be ready for LHC's 2009 run
- Tune and coupling feedback is evolving to chromaticity feedback
- LHC AC Dipole is mostly in the hands of CERN,
  - US scientists ready to participate and continue to develop "local" systems

Three tasks successfully completed in FY08

- Maintain a minimum level of funding to support LHC beam commissioning

One new task added for FY09

- LLRF modeling for the LHC

# Schottky Monitors Status

Project complete

- Documentation delivered

One trip taken in June to complete hardware commissioning

Waiting for beam

Early circulating team likely have gave signals

CERN staff if monitoring the devices

LAFS integrating software interfaces

# Schottky Hardware Commissioning at CERN

Tested:

The hardware control interface and cabling.

all switches, amps, attenuators in situ.

The scope was installed, but it did not have a working interface at the time.

CERN combined the Labview software from Fermilab for controlling amps, switches, attenuators with Labview software written at CERN to control the DAB board and FFT.

As a final test of the system, we demonstrated remote control of most of the hardware from the meeting room (except MUX and front end phase shifter and attenuator).

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# Schottky Next Steps

- Complete hardware for automation of measurements
  - Part of CERN's original responsibility
  - Motor control drivers for the front end phase shifter and variable attenuator.
  - Signal multiplexer for timing channels to the oscilloscope.
- Develop automation software
  - LAFS could help
- LARP (FNAL) ready to take beam commissioning trip(s) in support of device operations

# Chromaticity Tracking - History

Objective: Develop chromaticity tracking during ramp and store

Tune and Coupling Feedback

- Simultaneous Tune and Coupling feedback used in RHIC run 6
- RHIC run 7 and 8 - Tune and Coupling feedback operational
- Task ended in FY07

P. Cameron now working at NSLS-II

- Available to participate in short term visits

CY Tan (FNAL) now leads the activity

# Chromaticity Tracking and Feedback

Challenge:

- persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka "snapback")
  - Betatron tunes ($Q_{x,y}$) and chromaticities ($Q'_{x,y}=EdQ_{x,y}/dE$) can vary significantly due to "snapback" resulting in beam loss, emittance growth.
- Effects for LHC predicted to be large.

Solution: make fast, precision Q, Q' measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

This effort is ideally suited for a collaboration with RHIC, which can be the benchmark and testing ground for this effort.

- slow (1Hz) radial (1mm) modulation
- faster phase modulation

# Plans for FY09

1. Continuous head-tail

Machine studies at the SPS during the first week of November where head-tail data will be collected

Participate remotely using LHC@FNAL and will analyse the data.

2. Phase modulation method

The method has been recently made operational in the Tevatron.

A write up of the technique will be made to the collaborators very soon.

3. Travel to CERN
   - tune tracker, chromaticity tracker commissioning
   - machine studies for continuous head-tail.

# AC Dipole

Started in FY07 under by S. Kopp (UT, Austin)

FNAL graduate student -- now Toohig fellow

with support from FNAL scientists

VERY active involvement from BNL, FNAL and CERN

All three labs have AC dipole activities

All labs contributing resources to make it happen

LARP committed to develop concepts on US colliders and provide system description for CERN to implement in LHC

# Status of AC dipole

All collider labs actively involved

- FNAL implemented a system (aka musical dipoles)
  - –Tested non linear optics at Tevatrons injection
  - –Part of Ryoichi's PhD work
- BNL developing a high Q power system as a supply for these applications
- CERN has own group and has built a system
  - –Benefit from LARP's experience

Mei Bai new task leader

Ryoichi now a Toohig fellow at BNL

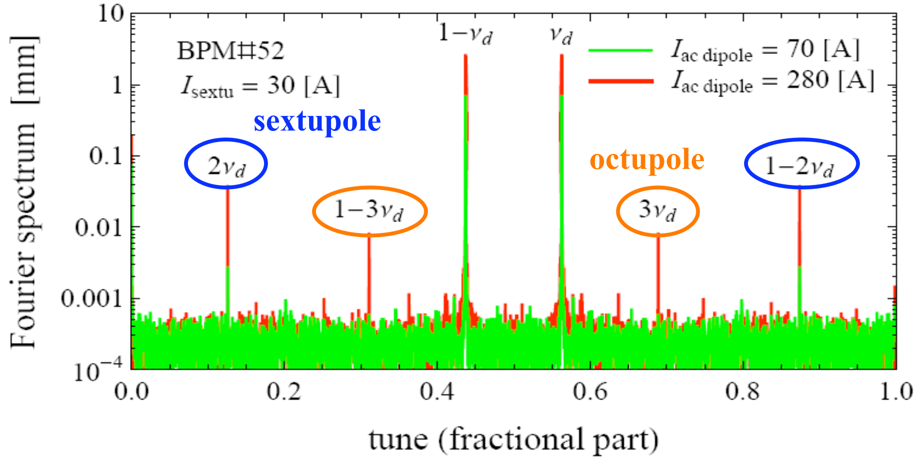
FY09:

- –Plan to perform design studies at BNL for validation of measurement methods in preparation of LHC commissioning
- –Participate in LHC commissioning

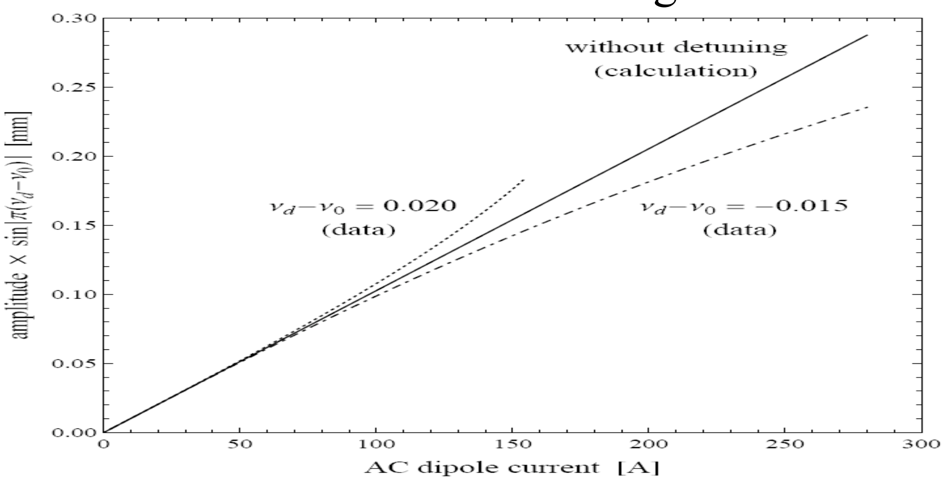
# AC Dipole Task, FY08 Activity

## • Tev. Nonlinear Dynamics Study (FNAL)

Spectrum of TBT data tells distribution of nonlinear driving terms in a ring.



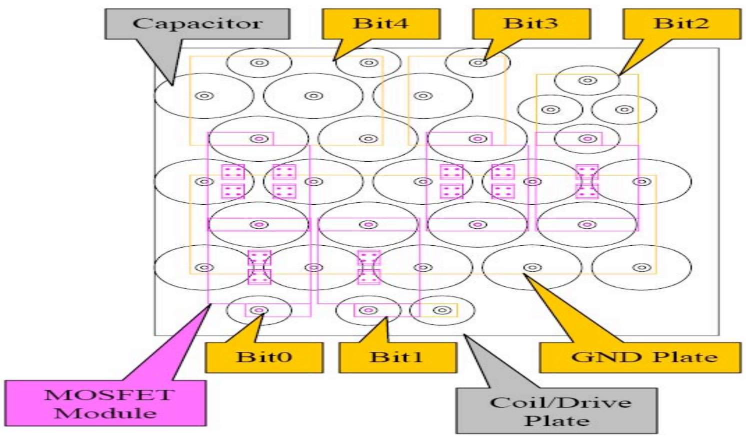

Measurement of Amplitude modulation due to detuning




(Details in PhD thesis of R. Miyamoto)

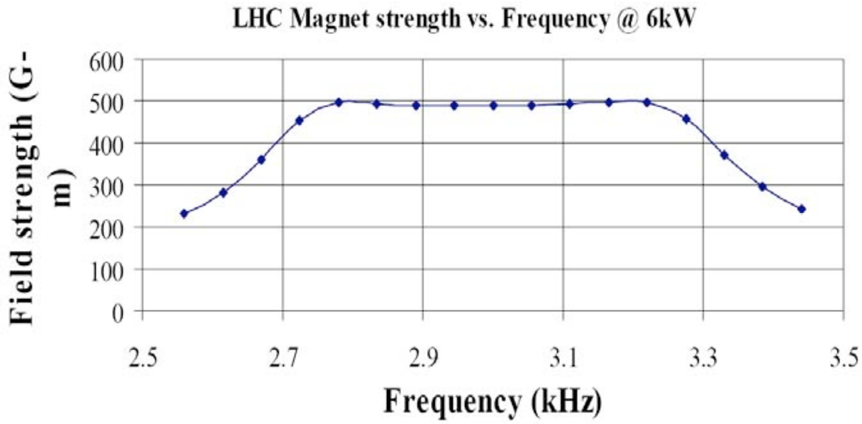
## • AC Dipole Tuning Scheme (BNL)

Capacitor bank allows ±15% (0.255 - 0.345 in tune, 2.867-3.880kHz) of tuning rang.




## • Further Development of Tuning Scheme (BNL)

A dynamic tuning technique using single switched capacitor (simulation).



# AC Dipole Task, Plan in FY09

## Focusing on Commissioning

- LHC AC dipole system to achieve the design goal of delivering 1800 Amps @ 3kHz
- Control software

## Development of Measurement Technique/Application

- Linear optics measurement
  - A lot of data have been taken in RHIC and Tevatron
  - Help the development of LHC on-line optics measurement/gradient error correction application such as SVD and MIA
- Dynamic aperture measurement
- Non-linear resonance driving term measurement

# New Task - LHC LLRF Modeling

Lead by SLAC (J. Fox)

Apply extensive modeling experience developed and tested in PEP-II to
- understand the LHC RF controls
- identify optimal operating point
- determine weaknesses and derive solutions

J. Fox and others from SLAC already involved in hardware commissioning and testing in 2008

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# LHC LLRF Modeling

Scope of work:

- PEP-II and LHC LLRF systems are very similar
- LHC work fits into two related activities:
  - RF Station/Beam Dynamics Interaction Model
  - LLRF Commissioning and optimal configuration tools
    - Allows estimation of open-loop stability margins from closed-loop data. Model based station configuration allows station and beam dynamics to be optimally configured in operating stations with beam.

# LHC LLRF Plans FY 2009

Expand configuration tools for CERN use, including full LLRF controller (Direct and 1-Turn Feedback loops)

Participate in commissioning measurements

Validation of simulation

In depth beam/model verification

Study of imperfections, technology limits

Estimation of noise floors and impact on machine performance

Estimation of system limits

Longitudinal emittance analysis

Use simulation and commissioning experience to improve LLRF implementation.

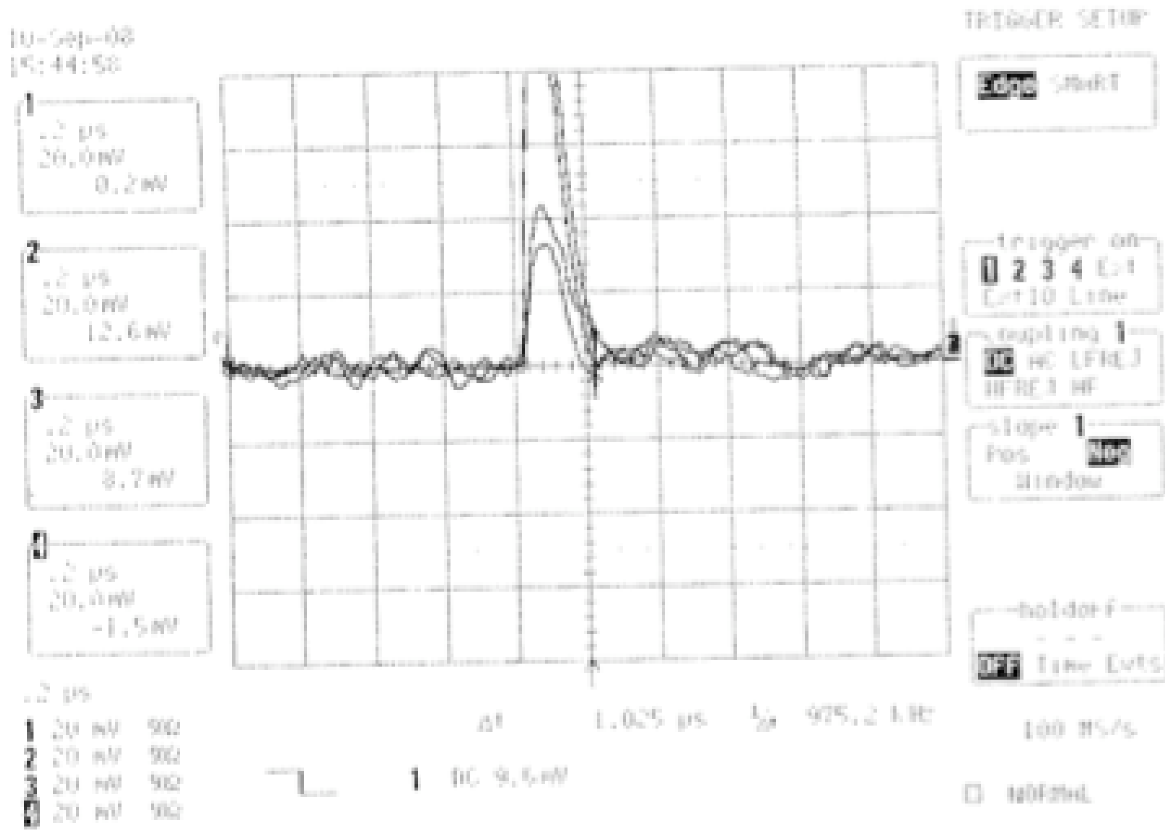
# Luminosity Monitor

Two separate activities:

1. Fabrication project -->deliver 4 detectors and all auxiliary equipment
   - Install well in advance of 2009 run
   - Well in advance = end of February 2009
   - Task to end in FY09

2. Physics studies and beam commissioning
   - Work will carry on into LHC operations

# First beam at CERN



Taking beam on Sep. 10 at PT5R

# Accomplishments in FY08

- Recorded first beam on day one
- Delivered four detectors to CERN
- Completed (simplified) gas systems
- Completed phase 1 firmware and software programming
- Systems integration underway

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# FY08 Highlights

HV cables performance
- Initial design had unexpected leaks
  - Caused noise comparable to actual lumi signals
- Resulted in the complete redesign of the flange/HV cable assembly

Recovered from HV cable leaks
- Now working on integration of PA and Detector

As we were developing a solution for HV cables, we completed the detectors
- Two shipped and installed in LHC in Spring
  - Adequate for low luminosity run in 2008
  - Must be retrofit to match final design
- Balance (2 more) at CERN ready for installation
  - New configuration completed in September

# HV Cable Problems

Original design implemented commercial rad-hard ($SiO_2$) cables
- very long lead items (6-9 months)

When connected to very sensitive charge pre-amplifiers a small number of charges migrating across the gap results in pulses like those from the detector

In many cases high rates (> 100 Hz)
- not acceptable

Unexpected, passed all project reviews

Resulted in the decision to design cables ad-hoc

# New Cable Design

Strong boundary conditions:

- sustain GRad-doses of radiation
- 50 Ohms configuration
- no HV leaks
- no long lead items, or custom designed parts
- no gas volume to act as detector
- fit in existing space to prevent re-design/manufacturing of existing detector parts

Engineered a solution using COTS

- 5 kV commercial feed-throughs
- glass and ceramic insulators
- standard copper tubes

# GAS Systems

Reduced scope to conserve money

- No active pressure/flow control
- Simple readout system

Delivered to CERN in June

Installed by CERN both at pt1 and pt5

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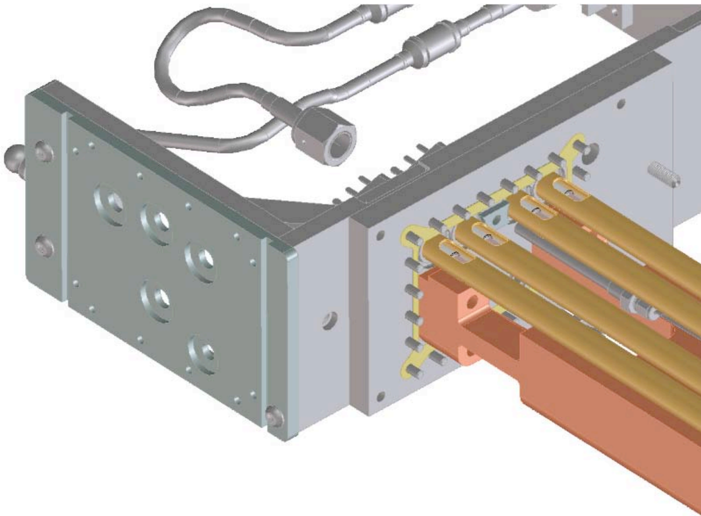
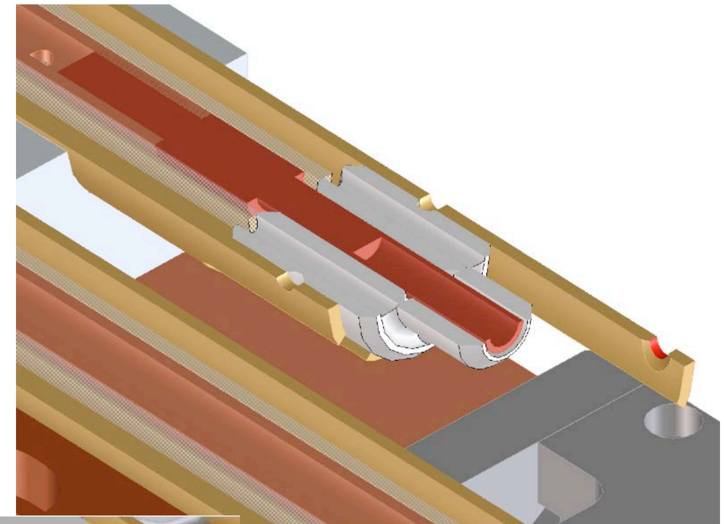
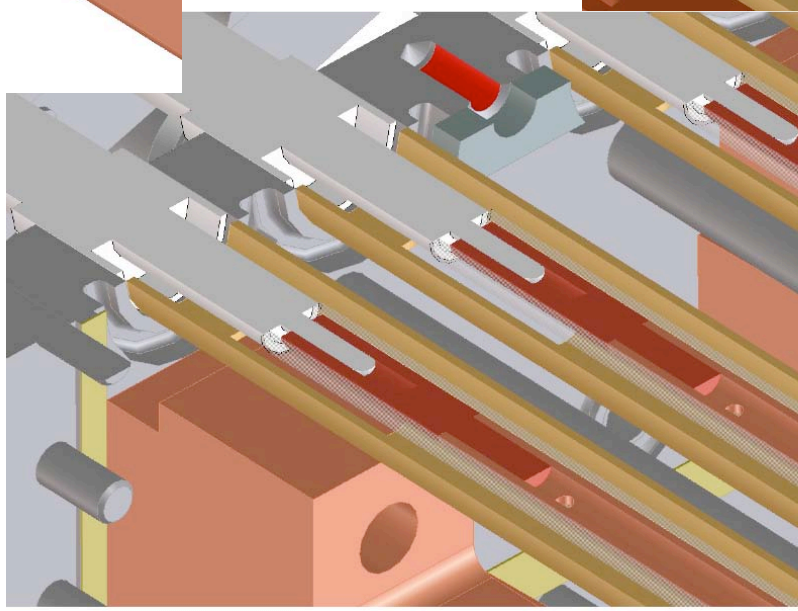
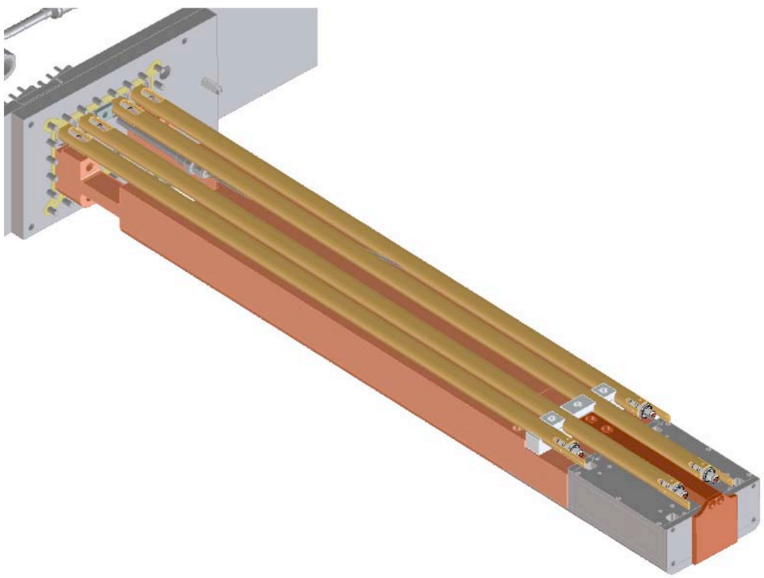
# Detector Assembly with new cables

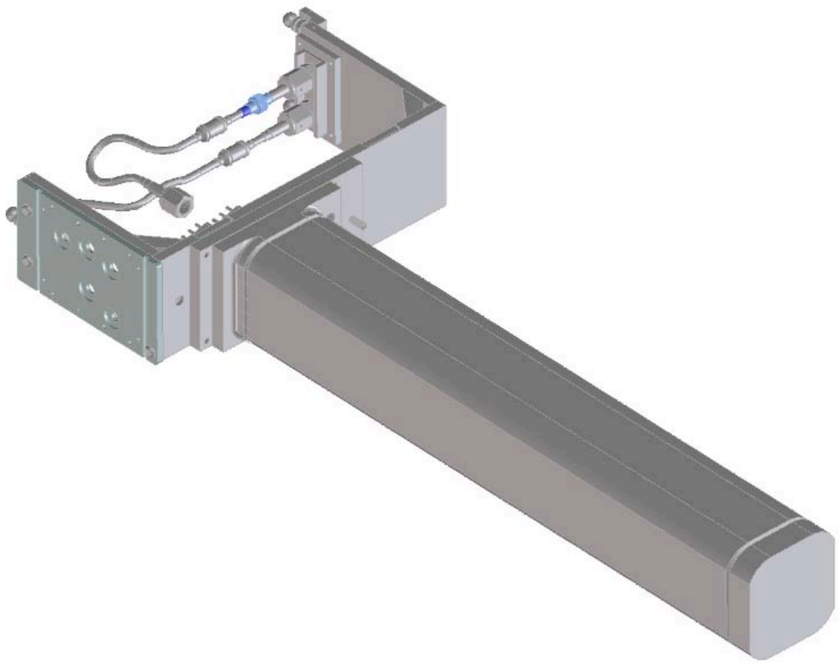






# Detector Assembly

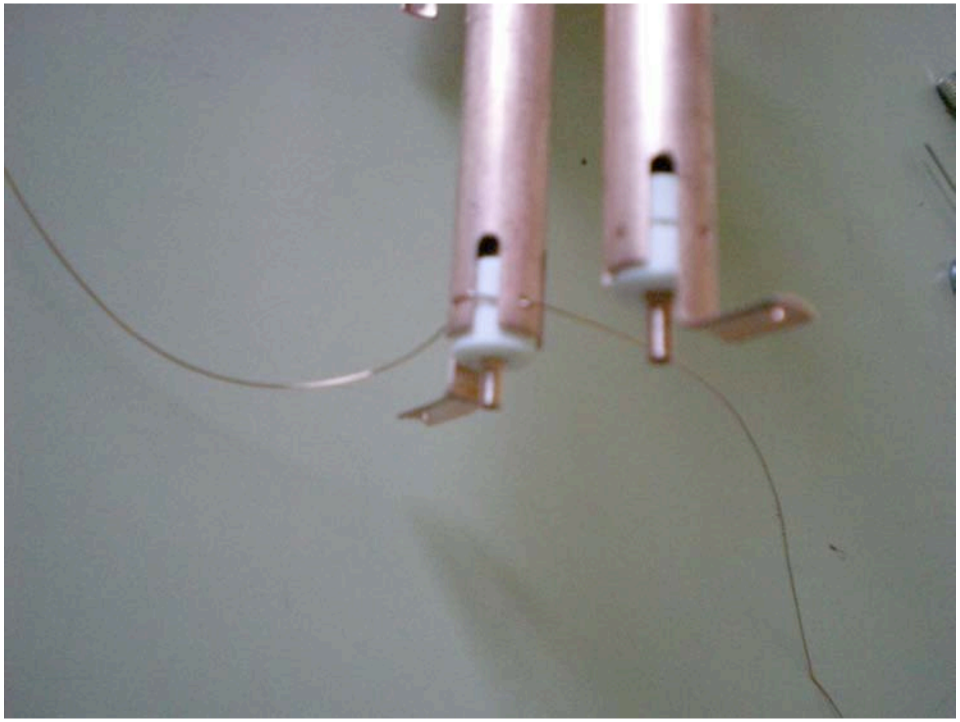




# Detector Assembly - 1

1. Install inner conductors, glass and ceramic insulators

2. Safety wiring holds ceramic stops

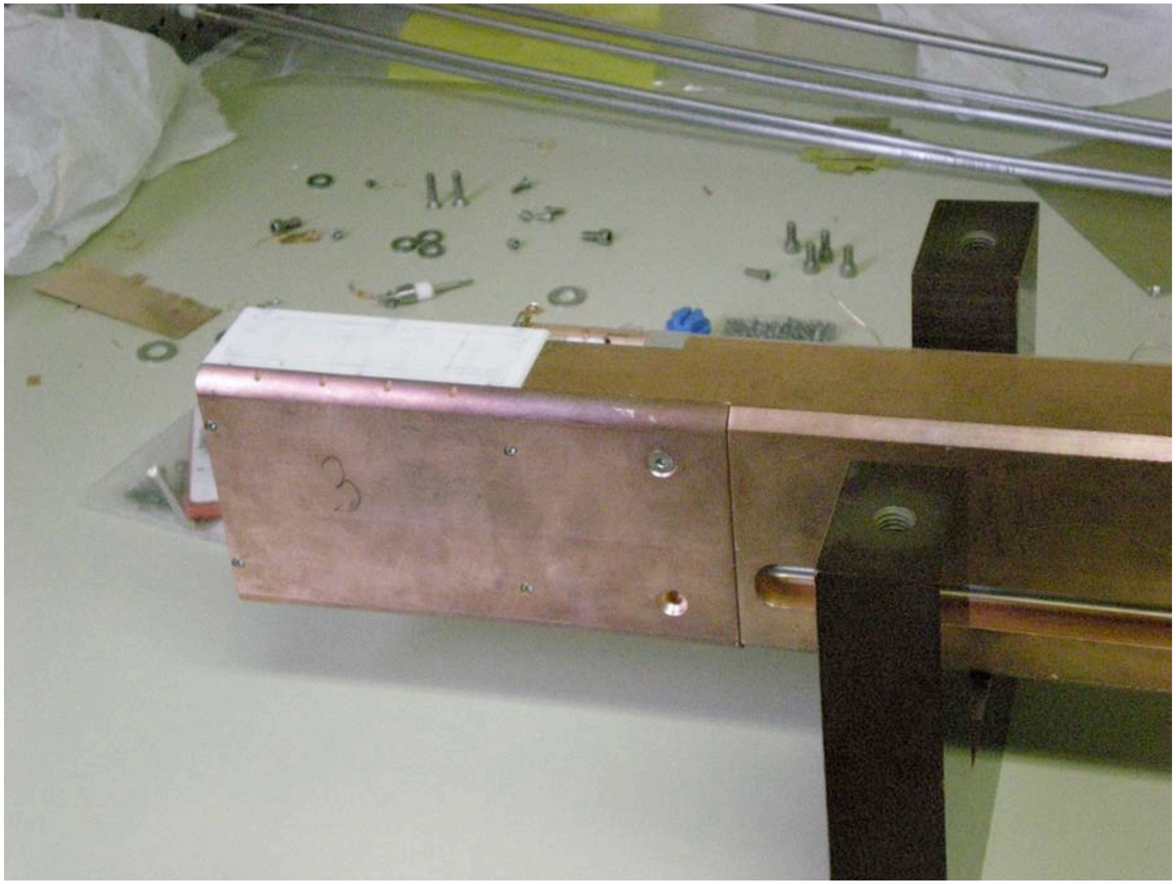


# Detector Assembly - 2

3. Mount copper support block to flange

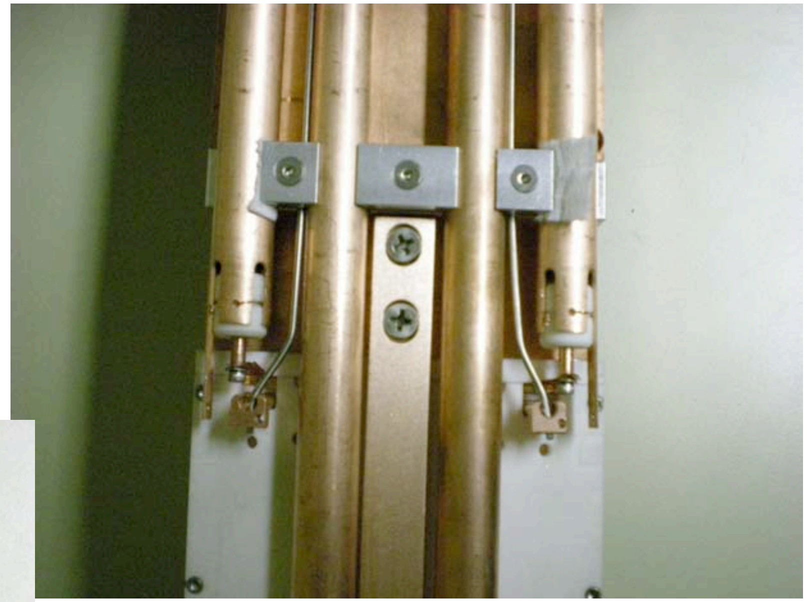
    Gas feedline connected

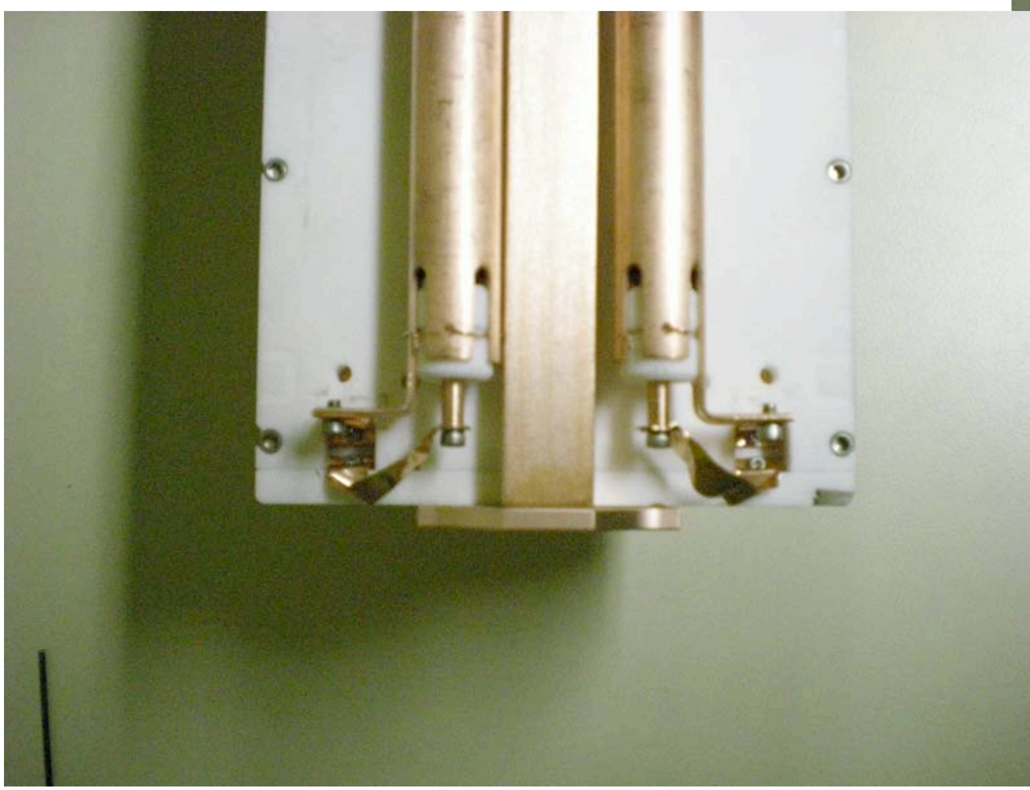
4. Mount sensor assembly on copper support block



# Detector Assembly - 3

5. Custom made connections to each quadrant





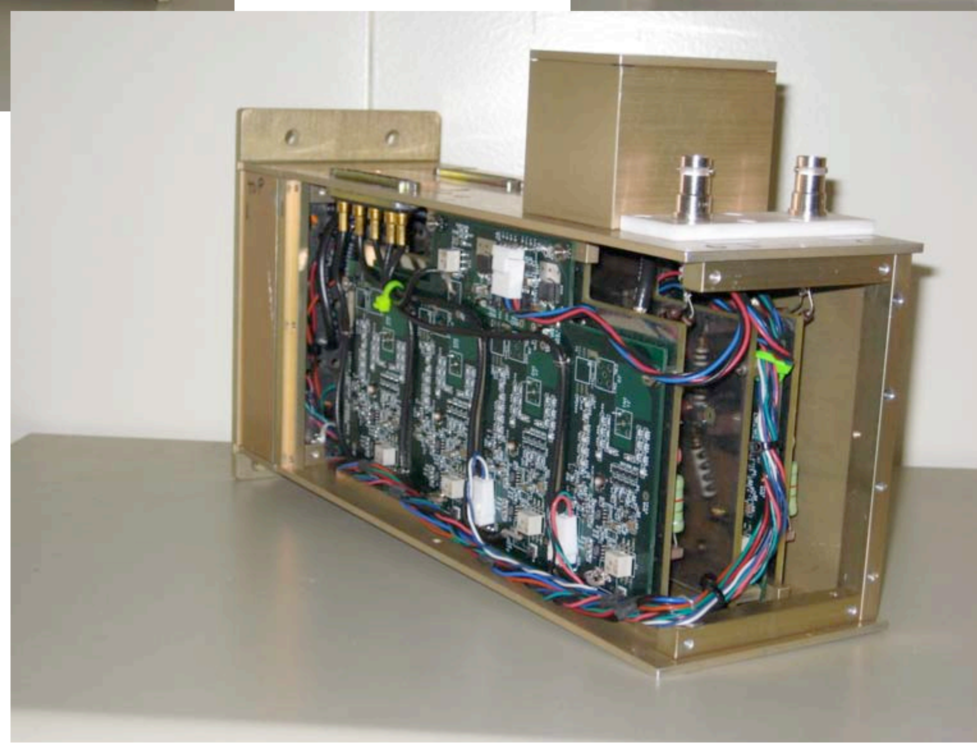
Adjusted for HV performance

# Detector Assembly - 4


Install on housing

TiN seal

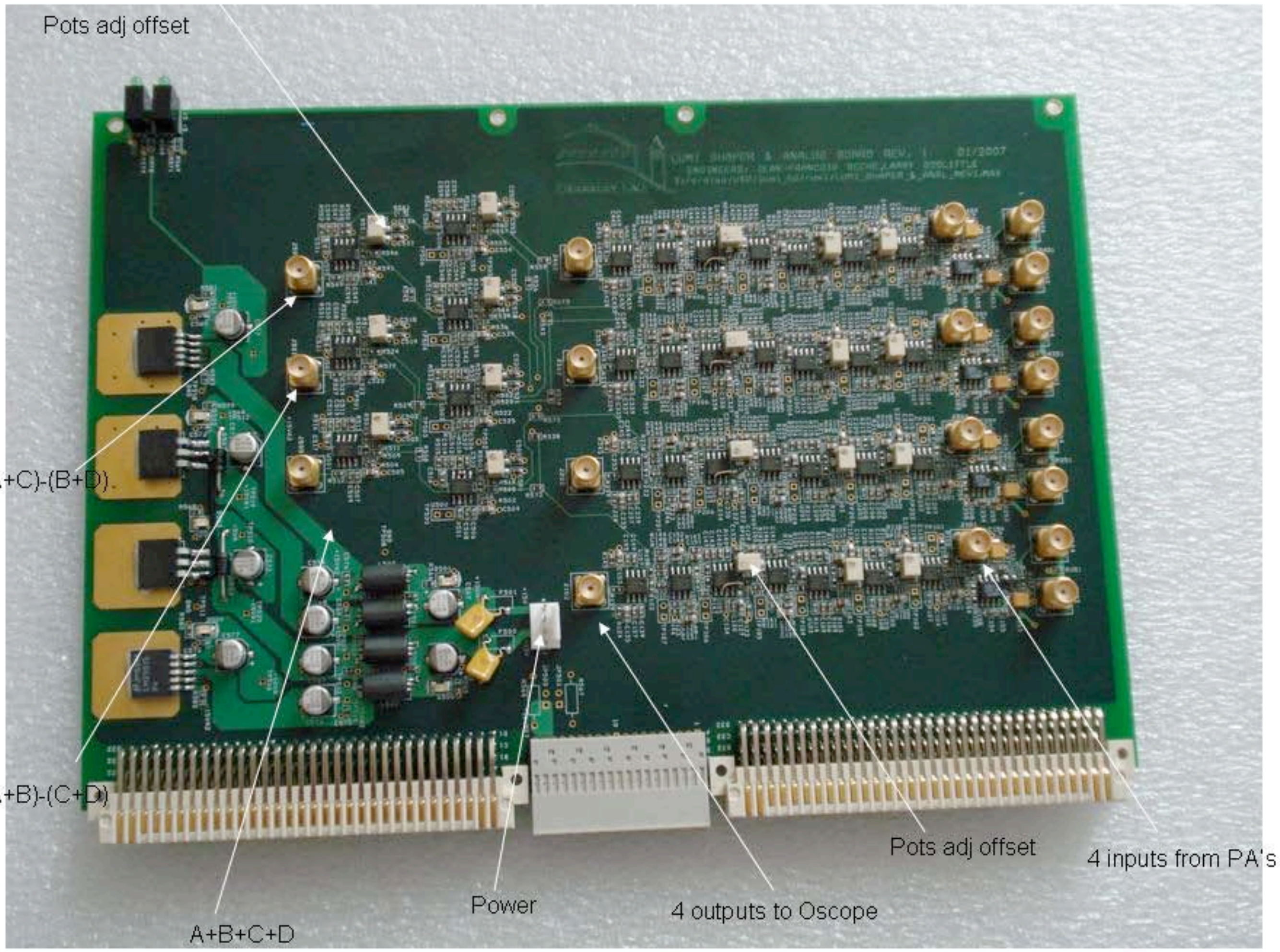
# Pre-Amplifier Assembly



# Pre-Amplifier Production

- PA Assembly process
  - PA board loaded by vendor
  - Load HV board
  - Mate HV board to PA board
  - Fab and mount shield board
  - Connect HV relays board and compartment
  - Wire 28 pin Burndy connector
    - 4x2 DC bias supplies, 3x3 RTD signals, 4+2 Relay selector bias, 5 BJT damage
- All parts at LBL (need shield boards)
- Several cleaning steps and slow soldering of ground shields to maintain HV performance
- 6-8 days per unit

# Electronics - Shapers



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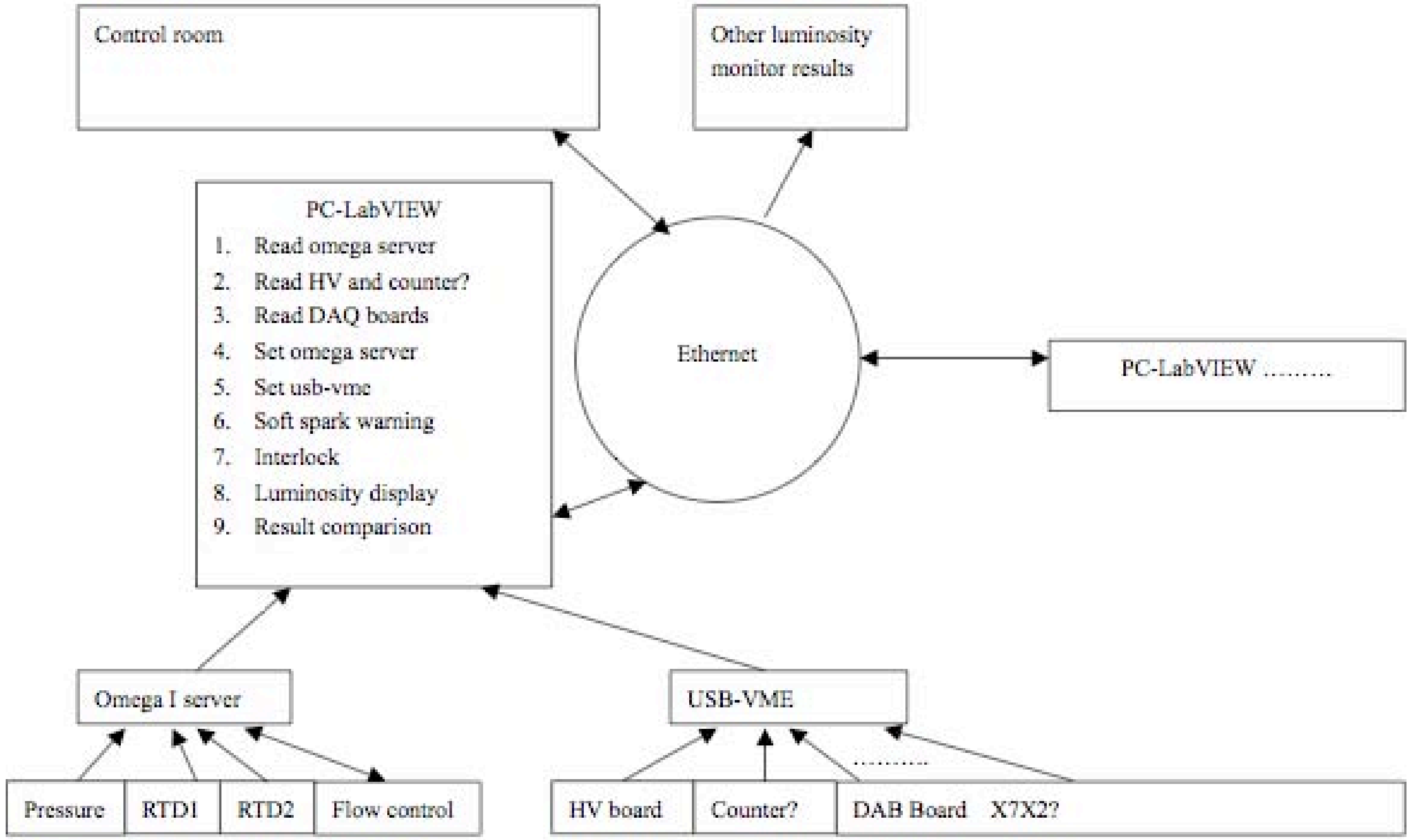
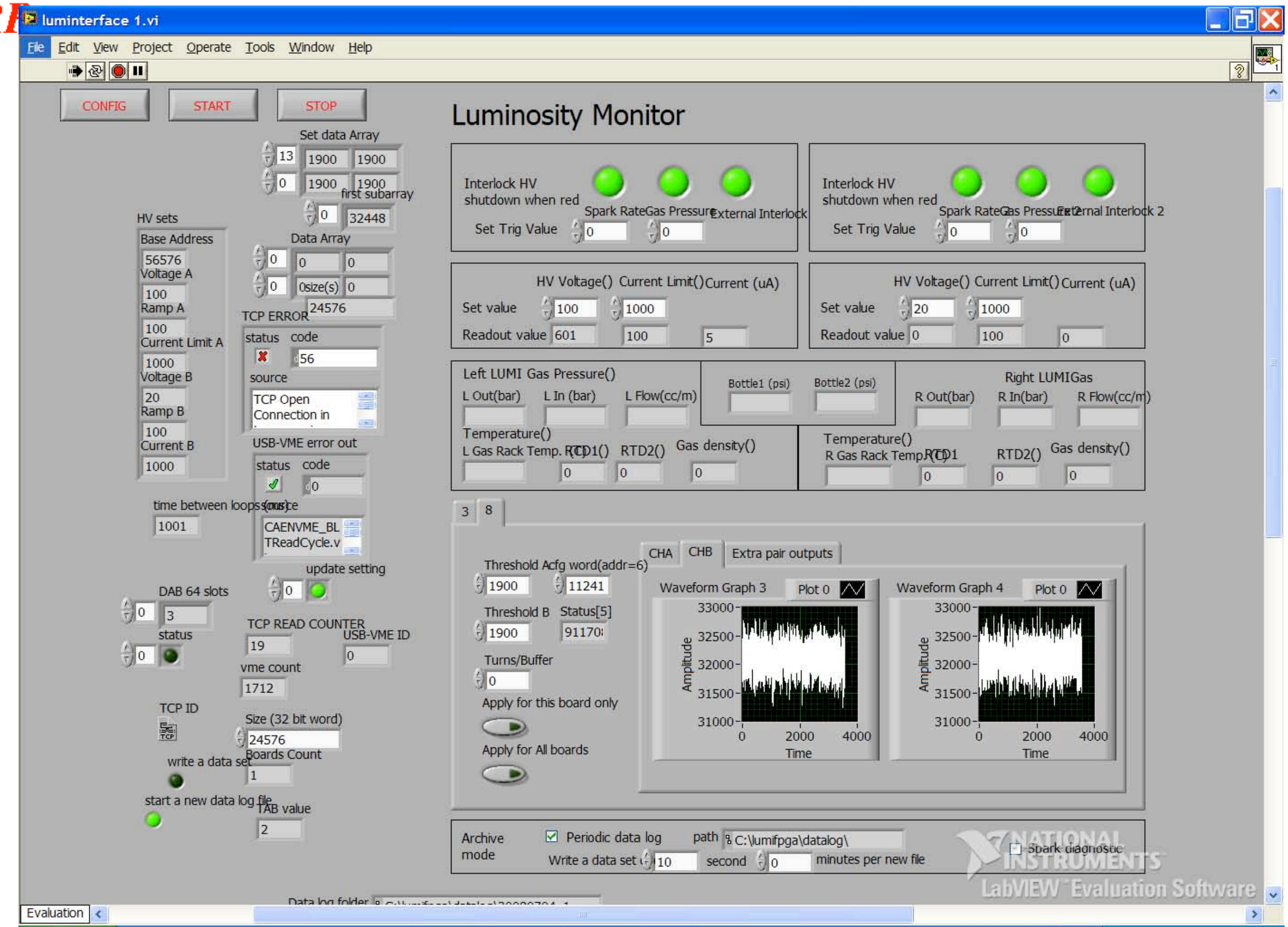
# Shapers - Plans

- Package in separate chassis
  - Control noise and interference
  - Does not require VME installation
  - Needs independent power supply
- Bench test and integrate with Pre-Amps
- Need 2 per IP, 4 total
  - Will assemble one spare

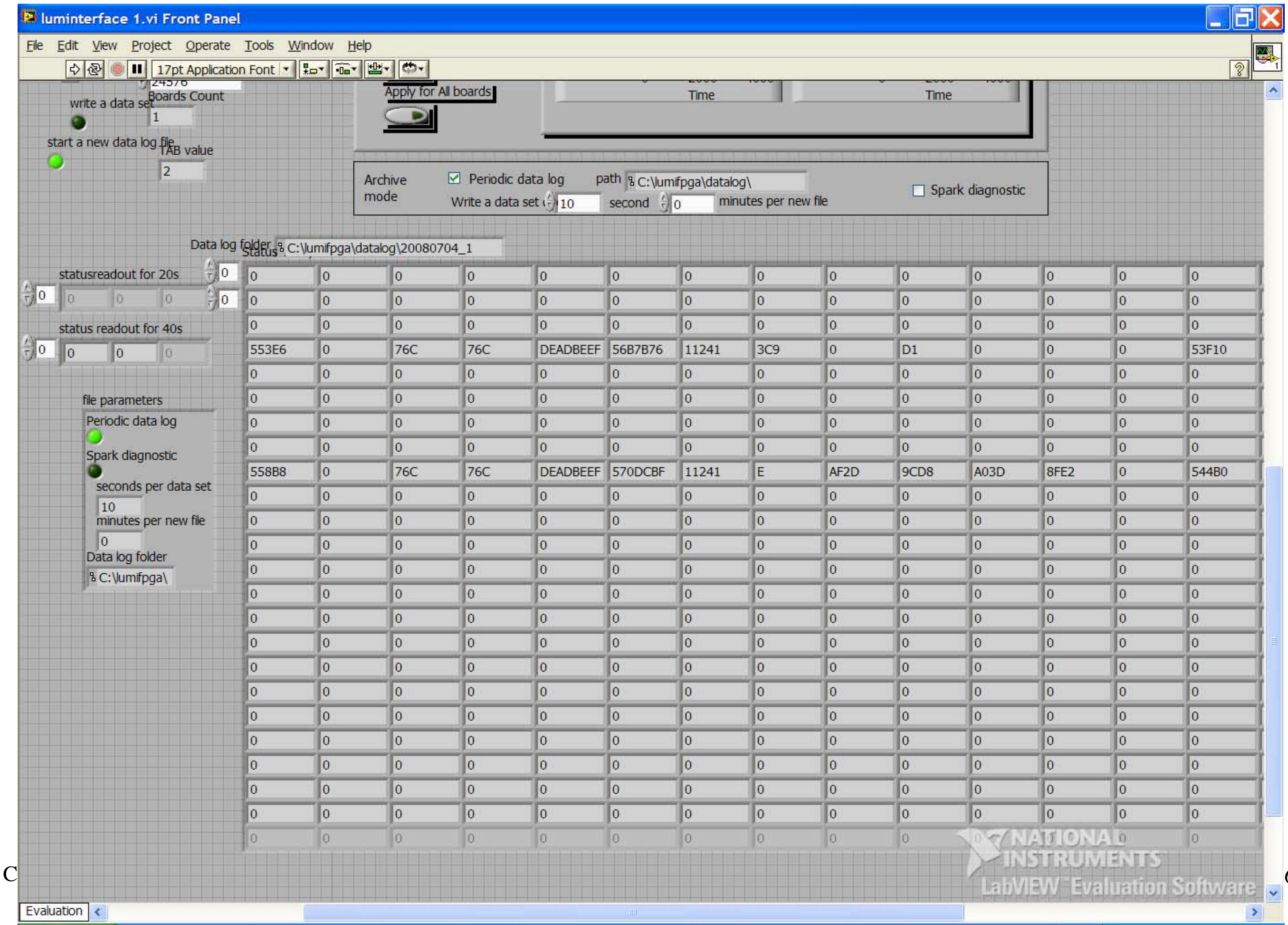
# DAQ System Layout



# DAQ programming

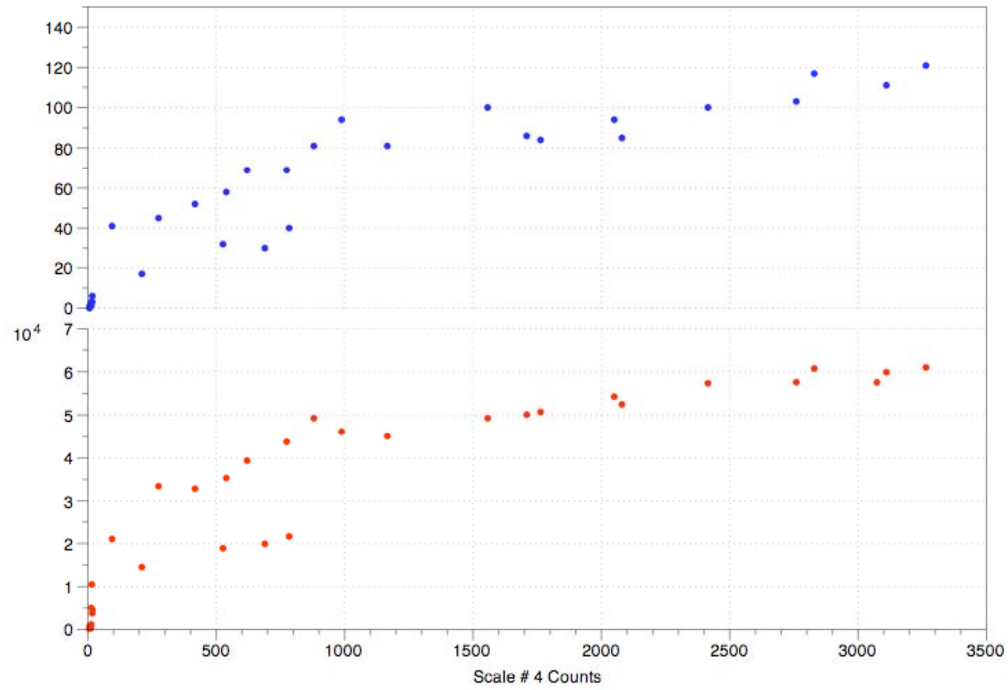


# DAQ interface panel



# Test during SPS beam test

- First test in the SPS
  - Good agreement with NIM scalers
  - Some adjustment required
- Learned we need an even/odd gain and offset adjustment
  - IBMS boards have two digitizers each



# Detector-PA Integration

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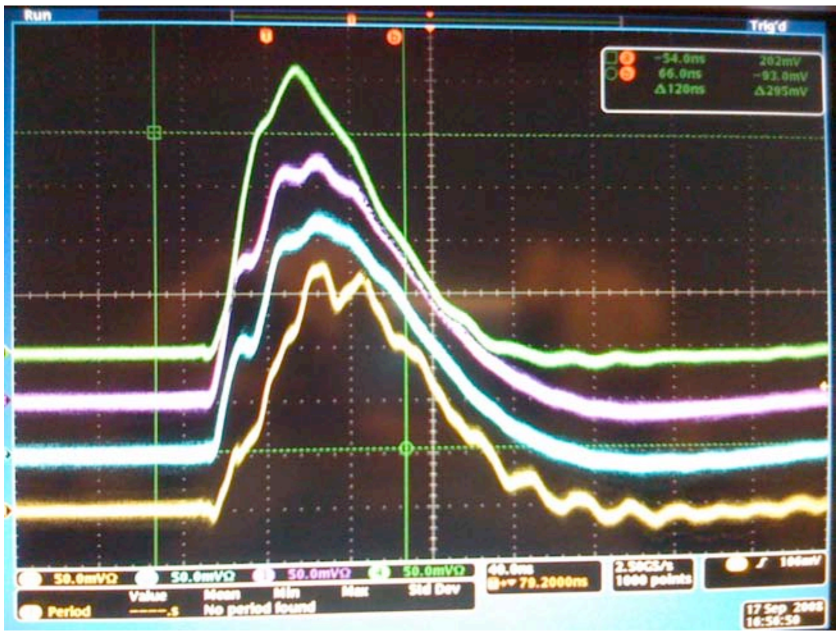
Detector - Pre-Amp studies

- Understand interdependencies
- Optimize configuration

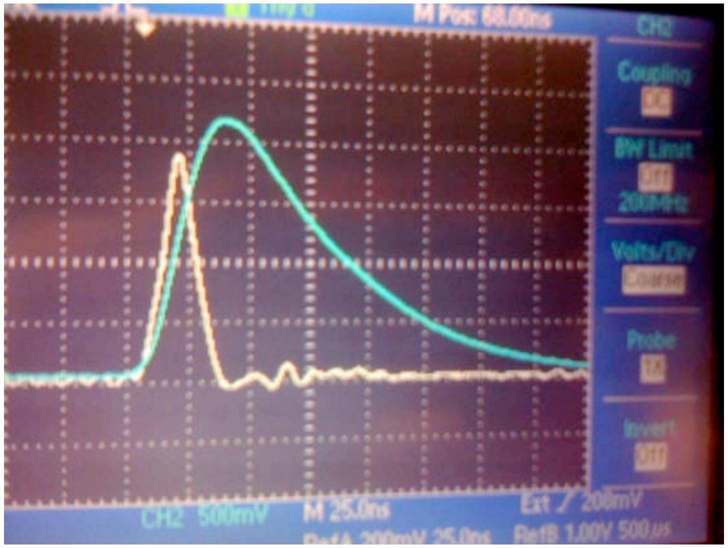


Test pulse - with and without load (detector)

# Pre-Amp Shaper Integration

## Pre-Amp Shaper studies

- Optimize => minimize peaking time
- Package shaper in shielded box
- Study interaction with PA
- Study/measure effect of long cable



# Detector Testing @ ALS

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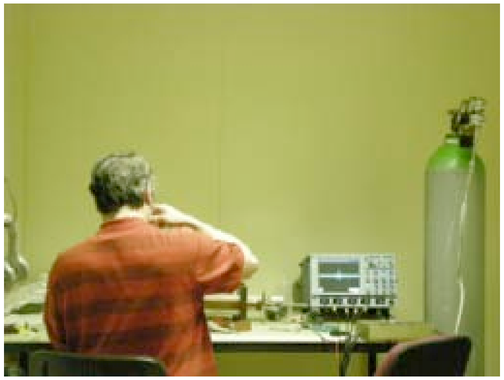
Since LHC beam returns in 2009 we plan to test the (spare) detector @ ALS BTS line in November-December

- Validate new cable configuration on ALS beam
- Test cable performance with high intensity signals
- Infrastructure available from previous test
  - 2 axis table, gas lines, signal lines
- Important to coordinate with analog electronics integration
  - Only one spare available

# Installation and Commissioning

Installation planned in collaboration with LHCf, Atlas and CMS ZDCs thanks to CERN's TS/LEA group



Extensive effort at CERN in integration activities

- Have office + lab at CERN
- A team account to support local expenses

CERN (Enrico's group) increasingly involved

LHC commissioning team starting to get involved

- Optimization of collisions

SLAC LTV (A. Fisher) available to participate to beam commissioning at CERN

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# Handoff to CERN

- CERN has been involved with many aspects of systems
  - Increased presence since 2007
    - Contributions to detector rework and optimization
    - Gas systems installation and commissioning
- Inviting CERN to participate to Berkeley activities (visit in Nov.-Dec.)
  - Beam test at ALS --> detector operation
  - Bench test of DAQ phase I firmware
  - Analog electronics modules production and testing
    - pre-amp and shaper
- Plan to continue during installation an HW commissioning at CERN
- Continue CERN's involvement in firmware development during phase II programming

# Luminosity Monitor Commissioning Plans

Commissioning will continue with each change in LHC operating conditions

- Since LHC won't reach nominal luminosity, must continue commissioning BRAN in FY10

Plan dependent on luminosity and fill pattern

Need simulations at each LHC energy

Need presence of personnel at CERN

Will take effort to make BRAN part of LHC beam instrumentation

# Stages to Maximum LHC Luminosity
# CERN EDMS 347396

| Mode | Bunches | Bunch Spacing | Luminosity [$cm^{-2}$ $s^{-1}$] | Interactions/Xsing | Mean pulse height/occupied bunch Xsing - mV |
|---|---|---|---|---|---|
| A–Collision studies with single pilot bunch beam - no crossing angle | 1 | N/A | $2.5 \cdot 10^{26}$ - $3.7 \cdot 10^{27}$ | 0.0006-0.092 | 0.04-0.53 |
| B–Collision studies with single higher intensity bunch - no crossing angle | 1 | N/A | $1.1 \cdot 10^{29}$ - $4.3 \cdot 10^{30}$ | 0.27-10.71 | 16-611 |
| C–Early p-p luminosity | 43 | 2.025 μs | $4.8 \cdot 10^{30}$ - $8.4 \cdot 10^{31}$ | 0.28-4.86 | 15-277 |
| | 2808 | 25 ns | $6.5 \cdot 10^{32}$ | 0.58 | 33 |
| | 936 | 75 ns | $1.8 \cdot 10^{33}$ | 4.79 | 273 |
| D–Nominal p-p luminosity | 2808 | 25 ns | $1.0 \cdot 10^{34}$ | 8.87 | 506 |
| E–Ultimate p-p luminosity | 2808 | 25 ns | $2.3 \cdot 10^{34}$ | 20.39 | 1163 |

Pressure = 8 atm - (57 mV for each 7 TeV collision)

# BRAN Instrument Commissioning Plan

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A–Collision studies with single pilot bunch beam - no crossing angle

- Collision rate too low to use as a luminosity monitor
- Minimize noise
- Get baseline software and hardware ready
- Study beam background (beam-gas, neutron ...)

B–Collision studies with single higher intensity bunch - no crossing angle

- Start in pulse counting mode
- Transition to pulse height mode
- Plan for crossing angle algorithms
- Need sustained presence at CERN

C–Early p-p luminosity

- Develop deconvolution algorithms
- May need deconvolution for this phase
- Study crossing angle algorithms
- Still in counting mode for most of this period
- Develop pulse height mode algorithms

D–Nominal p-p luminosity

- Pulse height mode
- Deconvolution
- Detector needs to fully commissioned with gas flow

E–Ultimate p-p luminosity

- Might need to lower pressure to reduce signal strength

# Mode A + B-Circulating Beam

- Measure noise rates and compare to expected
- Measure interactions
  - beam halo with beam pipe
  - beam gas
  - collimator
- Synchronize DAQ
- Measure for occupied and unoccupied bunches
  - pulse height
  - pulse shape
- Compare to simulations

## Mode C – Collisions

Synchronize DAQ and LHC clock

Measure counting rates as a function of measured voltage

Determine threshold for pulse counting

Verify bunch pattern

Compare luminosity measurement with other detectors

Analyze beam background

Develop and test deconvolution algorithms

Compare to simulations

# Mode D – Nominal luminosity

- Transition to pulse height counting mode
  - Compare to counting mode
  - Cross correlate with other luminosity detectors
  - Compare with simulation and expected fill pattern
- Study crossing angle calculation
  - Test and calibrate with LHC beam

# Lumi FY09 Beam Commissioning Plans

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Commission detector with beam

Cross correlate with PMT luminosity system

Integrate DAQ into LHC control system

Compare with models

# Summary

LARP Instrumentation has delivered and will commission into LHC operations advanced instrumentation and diagnostics for helping the machine

- reach design energy
- reach design luminosity

Strong collaborative efforts are in place and evolving

- Tune feedback is fully leveraging RHIC experience and includes CERN staff
- Lumi testing in RHIC is extremely valuable, CERN involvement increasing
- Schottky's experience at FNAL is a great asset
- US colliders are an essential test bed for system development

This program will advance the US HEP program by

- Enhancing US accelerator skills
- Developing advanced diagnostic techniques that will apply to present and future US programs
- Help maximize LHC performance